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# GOALI: A Hybrid Method to Support Natural Interaction of Parts in a Virtual Environment

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**Abstract**: The overall goal of this research is to improve the design of assembly methods through the use of virtual reality (VR) and haptics (force feedback). The research is focused on two critical aspects: the development of methods for simulating natural part-to-part interaction to support the human-centric approach to concurrent design and the evaluation of these methods in a manufacturing design context. As part of the research, we have developed the SPARTA software platform, explored new VR interaction methods and conducted several site visits at Deere facilities to better understand their processes and operations. This paper summarizes the efforts and results to date.

**1. Introduction:** Virtual reality (VR) technology has progressed from strictly walk-through simulations to support for truly interactive environments. In an engineering context, users who are instrumented with position tracking devices in a virtual environment are able to reach out, grab parts and manipulate them in a natural way while viewing life-size stereo images. This ability to manipulate parts, while still in their digital form, has the potential for significant impact on engineering decision making. However, a gap exists in our ability to simulate the interaction of parts with other parts in the virtual environment. The proposed research will address this gap in partnership with colleagues from Deere & Company. The research will result in a new hybrid method of collision detection and haptic modeling that will more realistically simulate natural interaction of parts in a virtual environment. This system will be human-centered and thereby incorporate human motion and decision making in a manner that traditional computer systems do not. A major component of this research will be a study to evaluate the effectiveness of these methods to support a VR environment for assembly methods validation.

Over the years, engineers have recognized the need to consider manufacturing, assembly, maintenance, and training aspects of products early in the product design process. While CAD models accurately represent the geometry of parts, and can be used to examine some aspects of part assembly, CAD systems do not take into account how humans interact with the product during assembly or maintenance. Virtual reality technology provides a unique set of tools to support human-centric design early in the design process. The key to realizing this potential is simulation of natural part interactions, including force feedback, or haptics, as parts are assembled or disassembled. In this research we have undertaken two major tasks: 1) research to develop a unique new algorithm to simulate natural part interactions in a virtual environment that is based on a hybrid voxel/boundary representation with haptics, and 2) evaluation of the effectiveness of the natural part interaction methods as applied specifically to assembly methods validation. In the evaluation phase, we will use relevant assembly scenarios taken from current Deere product lines to populate our evaluation tests.

**2. Background:** A human-centric approach is one where the traditional computer interface is replaced with a human- computer interface that is essentially transparent to the user. The monitor, mouse and keyboard are replaced with large stereo projection screens or head-mounted displays (HMD), three-dimensional (3D) position trackers and input devices such as gloves or wands that together create a virtual environment (VE). In this environment, users interact with the computer simulations using natural human motions such as walking, moving, squatting, head turning, and grasping.

Obtaining digital representations that are presented in real size is important to our efforts to provide an immersive environment to evaluate assembly methods. Using VR, a tractor frame does not have to be scaled to fit within a 21 inch monitor, but can be presented in real size. It is the relationship between the operators and the CAD part models, fixtures, and facilities that form the core of our efforts. Both large stereo projection screens and HMDs support real size CAD display.

Theories of attention propose that as some tasks become natural and routine, more attention can be focused on other tasks [1]. In an engineering design context, it is our experience that providing an environment that supports natural interaction with digital products results in improved communication between members of the design team. Experts and non-experts can more thoroughly understand the form of the product design and discuss issues that might arise in design and manufacturing of the product. Judging sizes and spaces using traditional computer based tools is difficult and leads to errors in layout and planning resulting in increased product costs. Both the features of natural interaction and presenting products in true scale support increased understanding among members of the product design team.

One approach to building a human-centric environment is to insert digitally simulated humans within the virtual environment. While this approach is effective for evaluating some issues related to injury risk, fatigue and comfort, digital human modeling does not allow users to freely interact with the digital models as if the models were real parts. Human motions are scripted and replayed by the digital human simulations. This approach is more realistic than a traditional CAD assembly modeling approach but using digital human models does not avoid some errors that can exist do to misunderstanding of either the product or the production environment that occurs when a product finally goes into production.

The focus of this research is on the development of critical methods for simulating natural part-to-part interaction to support the human-centric approach to concurrent design. A key component of this research will be the evaluation of these methods in a manufacturing design context. As part of this component of the research, we have conducted several site visits at Deere facilities to better understand their processes and operations, which are necessary to guide our development of a virtual assembly environment.

There are many aspects of the product life cycle that contribute to the cost of a product, including research and development costs, production and distribution costs, operation and support costs, and retirement and disposal costs to name a few [2]. Production costs include costs related to product engineering, production planning, manufacturing, testing and quality control, marketing, and shipping. Concurrent engineering principles support design of the product with considerations for manufacturing and assembly issues. This integrated approach to product design has been shown to be cost effective and is therefore widely used in industry. In this approach, as a product is being designed, all people involved with the eventual product are involved from the initial conceptualization of the product on forward through the final product design [3].

For the manufacturing engineer, his/her role is to identify optimal production processes and assembly sequences. Assemblies can be very complex and can involve hundreds of parts. The role of the manufacturing engineer is to estimate assembly times, create sub-assemblies, design production layouts, and tooling in an effort to design the most effective production assembly operation. The result is an assembly plan that includes a floor layout of work stations along the assembly line, tooling designed to support the assembly process, and a step-by-step description of the tasks need to assemble the parts.

The effectiveness of this concurrent approach to design relies on the ability of all members of the design team to understand the design in its early form and identify potential problems. Parts are sometimes represented as sketches or simple CAD models. Decisions involving manufacturing and assembly depend entirely on the manufacturing engineer’s ability to understand the geometry of the product based on these initial product representations. As the product design process proceeds, various check points are reached where manufacturing assembly methods can be validated: at the virtual build (with CAD models), at the prototype build (with prototype parts), and at the first assembly build (with production parts). The manufacturing engineer who outlines the assembly instructions sometimes fails to visualize all pertinent aspects of the assembly process on the factory floor, both human and structural, possibly through errors in spatial judgment, lack of knowledge of the workspace, or the inherent ambiguity of complex assemblies. At each stage, when changes to the assembly plans are identified, a re-balance of the assembly line, modification to part geometry or modification to work cell layout might be required. Inadequate tooling, errors in assembly task descriptions, errors in subassembly partitioning, and the inability to reach parts in the assembly are some of the changes that often occur. Sometimes, when the part reaches first assembly, the assembly workers identify more efficient assembly methods that could have been used. As the product design becomes finalized, even minor changes to product geometry or production line layouts to accommodate changes in assembly methods are costly.

**3. Progress to Date:** This two-year project was funded beginning in August 2009. During this first phase of the research, we have conducted two site visits to two different John Deere facilities. In addition, we developed an initial prototype of the hybrid haptic rendering algorithm and have made considerable progress toward the development of a more intuitive and modular VE for assembly work.

To support the research, a software system was developed that provides a modular and extensible platform for future VR applications development. The Scriptable Platform for Advanced Research in Teaching and Assembly (SPARTA) is developed in C++ and Lua. This system utilizes existing VR technology, including VRJuggler [4], to support software development using traditional human-computer interaction (HCI) interfaces yet implementation on a wide variety of VR environments including single wall, multi-wall and HMD. The result is that researchers can develop one application and use text-based configuration files to specify the HCI environment at any time for demonstration and evaluation. The software is cross-platform and can run on Windows, Macintosh, and Linux. The modular object-oriented design of the software is such that adding support for additional devices is extremely easy and fast.

Our extensive experience in using haptic devices for in virtual assembly applications [5-9] has led us to conclude that using a six-degree-of-freedom haptic device for assembly prototyping is essential. Assembling parts is extremely difficult when only using a three degree-of-freedom device that essentially provides only point-to-surface force feedback. Torque feedback is critical when using two hands to manipulate a long part and place it into an assembly fixture. In 2009 we purchased a Haption Virtuose 6D35-45 which is a tabletop six-degree-of-freedom haptic device that has an optimal workspace of approximately 9 $ft^3$. During the course of this research we explored methods to expand the workspace of this device to allow operators to manipulate and assembly CAD models within a standard operator floor workspace of around 80 $ft^2$. The Bubble Technique, developed by Dominjon et al. [10, 11] proved to be an effective method of manipulation and navigation. We extended this method to support assembly methods and demonstrated it to our Deere colleagues.

To further understand the issues that arise in assembly planning, the research team visited two different Deere facilities in Iowa over the course of the last year. Each of these visits provided us with valuable insights to better inform our present and future work.

The first of these two visits was arranged as an opportunity for our team of researchers to begin building rapport with manufacturing engineers and gain familiarity with key terminology and processes used. This technique for beginning field research with rapport building and unobtrusive observation to better understand the people and environment is consistent with LeCompte’s recommendations on conducting ethnographic research [12].

Although this first visit was intended primarily as a stepping-stone into deeper research, our observations did identify several key factors that needed to be addressed in a VE in order for it to be successful. One of the biggest hurdles to the use of VR we found in this observation is that the currently available VR software tools require considerable CAD model refinement prior to implementation. In addition, during this process of modifying the CAD models, many of the current VR tools do not support kinematic motion modeling, making their use in identifying potential failure points difficult.

Estimating how facility constraints impact assembly methods is also difficult using current tools. Bringing large facility data into the VR environment is a challenge due to the large data sets and the need for interactive display and human interaction. Once again, significant modifications are needed to the data files to support their use in VR. Integrating these facility models with the CAD data is important.

Further, it was apparent that correctly planning the assembly methods was critical to cost containment for the company. Miscalculating the assembly time and/or misidentifying assembly tasks results in bottlenecks in the assembly process and significant cost to the company.

In our second visit to a Deere facility, we were given the opportunity to observe a day of virtual build walkthroughs where assembly design engineers received feedback on new assemblies from the line workers. The active participation of the shop floor operators is extremely valuable. Deere is involving the operators in the planning process in order to identify issues early so they can be resolved before the first production run.

Here, we were exposed to two different techniques that are used to communicate the assembly design to the line workers including a layout/blueprint tool and an animation of the assembly. We observed the limitations of using these tools and will use this knowledge to guide our future research.

**4. Plan of Work:** During the rest of the project we will continue to explore methods to support low clearance assembly in order to arrive at an application that is general and able to simulate assemble of any production CAD models. We will also explore methods to handle model complexity that require little or no preprocessing of data.

We are planning additional site visits in the coming year to gather data and further understand the complex issues related to assembly planning. We are planning a preliminary experiment using SPARTA to be run during this next year to evaluate our HCI implementation. Later we intend to run a similar study using Deere personnel. The results of these studies will provide us with valuable data on the effectiveness and use of VR for assembly methods planning.

**5. Summary:** We continue to progress toward our goals of developing methods to support assembly planning and evaluating virtual reality for assembly methods prototyping. We have developed a software platform from which can be used to test various approaches and we have gathered information that is guiding our plans for evaluation. In the coming year, we will conduct several user studies and the data we collect will inform future software developments to support an effective virtual environment for assembly methods. We believe that providing a full scale realistic way for assembly engineers and line operators to interact with CAD models will help them better design the assembly process, which will lead to more accurately estimating assembly times and methods and cost savings for companies.

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